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Feedback Techniques Using PID and PI-Intelligent For Greenhouse Temperature Control

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ABSTRACT: With the advent of sophisticated greenhouse technologies, computerized greenhouse has naturally become imperative. It has created new opportunities to manipulate the indoor environment according to the specific needs of plants. The temperature under greenhouse is the most influential factor on the plants. Usually, it has been closely correlated with the other climatic parameters. This paper examines new ways to control internal greenhouse temperature using two types of controllers: PID and PI-intelligent. The two controllers give good results, except that the PID requires a method of parameters identification, which should be valid for a large time as possible. It is therefore necessary to repeat the chosen identification technique face to change unexpected of external parameters. However, the PI-intelligent controller permits to keep the adjusted gain for a long time thanks to actualised identification and resulted by algebraic method. In order to visualize the evolution of climatic parameters in real time, a graphic interface has been developed.

KEYWORDS: Computerized Greenhouse, Climatic parameters, Control, PID controller, PI-intelligent.

I. INTRODUCTION

For several years, studies on greenhouse climate controlling have made a challenge of several research tasks. Many control methods are proposed in literature: (Rodríguez et al. (2001); Bennis et al. (2008)) designed a feedforward controller for greenhouse climate control based on physical models; optimal control approaches have been proposed (Ioslovich et al., (2009)). Adaptive control strategies for greenhouse temperature control have been addressed by (Berenguel et al., (2003)) and (Speetjens et al. (2009)). The recently introduced model free control is proposed to control the temperature under greenhouse. It is a simple but efficient technique for the nonlinear, unknown or partially known dynamics. While retaining the PID reduced computational cost, it is able to cope with general types of nonlinearities. Model free control has been proven to be a simple but very efficient nonlinear feedback technique for the unknown or partially known dynamics (Fliess et al. (2009); Fliess et al. (2013); Join et al. (2013); Lafont et al. (2013); Lafont et al. (2014), Choi et al. (2009)). We shall here use so-called intelligent PID (or i-PID). While retaining the PID reduced computational cost, it is able to cope with general types of nonlinearities. A precise relationship between i-PID and PIDs is given in (d'Andréa-Novel et al. (2010)). It particularly emphasizes the ease of tuning of i-PID gains and gives a clearcut explanation of the performance of usual PIDs.

Greenhouses were been designed for plant cultivation in controlled environmental conditions. Greenhouse cultivation has several advantages: it helps to maintain an optimal plant growth environment and protects the crops from pests and varying outdoor conditions. Therefore, the production in greenhouses becomes considerably sophisticated and excessively expensive. For that, the greenhouse growers who want to remain competitive need to maximize their investment through the better management of production conditions. In order to exploit the adequate opportunities for crops, it is necessary to control the system in automatic way. The introduction of automatic techniques using computer has been a major advance for agricultural production (Yang et al. (2013); Eredics (2009)). In fact, there are three basic components in a greenhouse climate control: sensors, computer, and actuators. Sensors were be used to collect information that are important for plant growth and actuators were be used to modify the collected information. The management of the greenhouse environment is strongly reliant on temperature variation. This later is the result of complex, interactive heat, mass exchanges between the inside air and the several elements of the greenhouse and the outside climatic parameters. The process depends on the structure of the greenhouse type, the state of the crop and the actuating control signals typically ventilation and heating which are able to modify the inside temperature conditions. The various orders (heating and ventilating) of a greenhouse aim at the spontaneous improvement of the internal climate, but this control is never complete. It is difficult in fact to act on an element of the environment without modifying another element.

In our laboratory, the studies showed that the inside temperature is the most influential parameters on the greenhouse (Ezzine et al. (2010)). However, the automatic climate control requires the development of appropriate control laws that are based on models representing linear and nonlinear system. We are therefore forced to make a study of the system to control the temperature under greenhouse. To fully exploit the enhanced possibilities for crop and resource management in greenhouse, it is indispensable to adjust and control variables with a remote automatic controlling (El Afou1 et al. (2013); El Afou2 et al. (2013); Guerbaoui et al. (2013)).

The result presented in this work is the implementation of a new control strategy of climatic parameters under greenhouse. The proposed strategy is the PI-intelligent controller which compared with a classical PID controller. The reader may consult the recent book (Van Straten et al. (2011)) for a comprehensive approach for modelling and for optimal control (Iya et al. (2009)) that falls within a framework of modelling/ identification/ control. The controller strategies are programmed using Matlab/Simulink software.

This paper is organized as follows: the following section describes the experimental framework of the argument. A brief presentation of model-free controller approach was presented. We describe the implementation of the controllers and present the main experimental results.

II. AN OVER VIEW OF THE EXPERIMENTAL GREENHOUSE

Figure 1 presents a schematic view of the greenhouse system. The establishment of the greenhouse was made in order to develop an integrated data acquisition system to control the inside climate. The system is linked to a computer (PC). Sensors and conditioning modules allow us to measure the different climatic parameters inside and outside the greenhouse. The acquisition and data processing has been developed by a multi-function card NI-6024E to control and manage complex measurements. This experimental greenhouse has been equipped with many sensors:

- Sensors of inside and outside temperature (LM35DZ), data are expressed in °C.
- Sensors of inside and outside humidity (HIH-4000-001), data are expressed in %.
- Sensor of carbon dioxide concentration (Figaro AM4 module), data are expressed in ppm and named CO_2.

In order to improve the climate under greenhouse, we have installed a heating system, pulsed air supply and a variable speed fan (Ed-Dahhak et al. (2007); Lachhab et al. (2007); Ed-Dahhak et al. (2009); Guerbaoui et al. (2011)).

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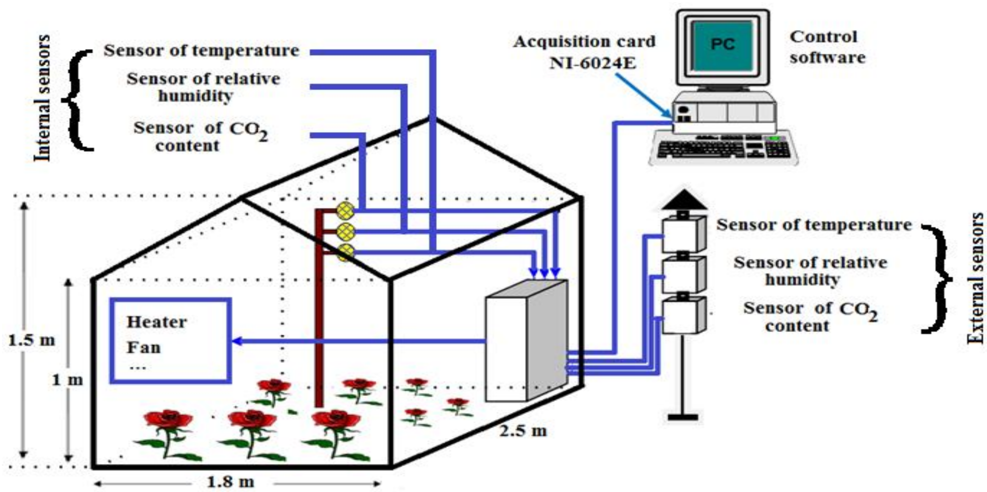

Fig. 1 Schematic view of the greenhouse system.

III. THEORITICAL STUDY OF THE USED CONTROLLERS

A. PID Controller

PID control is the method of feedback control that uses the Proportional, the Integral and the Derivative as the main tools (Hensel et al. 2012, Beshi et al. 2011 and 2012). The purpose of control is to make the process variable y(t) as a suitable value named set-point $y_r(t)$. To achieve this purpose, the manipulated variable u(t) is changed at the command of the controller. In the present application, the process variable y(t) is the temperature and the manipulated variable u(t) is the command of the controller. The “disturbance” is any factor, other than the manipulated variable, that influences the process variable. In some applications, however, a major disturbance enters the process in a different way, or plural disturbances need to be considered. The error e(t) is defined as: $e(t) = y_r(t) - y(t)$. Where, $y_r(t)$ is the desired trajectory and y(t) is the measured variable. The PID is a controller that takes the present, the past, and the future of the error into consideration. After digital implementation was introduced, a certain change of the control system structure was proposed and was adopted in many applications. However, that change doesn’t influence the essential part of the analysis and design of the PID controllers. The transfer function C(s) of the PID controller is:

$$C(s) = K_p + K_i \frac{1}{s} + K_d\, s \tag{1}$$

Where, K_p, K_i and K_d are positive parameters, which are respectively referred as “proportional gain”, “integral gain”, and “derivative gain”.

B. PI-intelligent controller

This section summarizes briefly the idea of model-free control, limited to the needs of this application, the monovariable case and the derivation of order 1. Readers might refer to the extensive bibliography on this topic, especially since the available items (Gédouin et al. (2011), Fliess (2008, 2009); Fliess et al. (2011); Abouaissa et al. (2011)) for the monovariable model-free control, and (Mboup et al. (2009), Liu et al. (2011)) for the derivative estimation. The model-free control is based on a local modelling of the system, from the only knowledge of its input-output, thus avoiding the sometimes-difficult steps of modelling and identification valid over wide operating range. It is based on algebraic techniques for estimating the derivatives of noisy signals to express the derivative signal $y^{(i)}(t)$ as an integral over a short interval [(t – T), t] who is developed in order one, It’s sufficient for this application. The estimation of this derivative can take the following form:

$$\hat{\dot{y}}(t) = -\frac{3!}{T^3}\int_0^T (T-2\theta)\, y(t-\theta)\, d\theta \tag{2}$$

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In practice, the equation (2) is evaluated at each sample time, t = kT_s, with k = 1, 2… and T = n_sT_s, with n_s is the number of samples, T_s is used in the time window T, as a discrete sum using basic discrete method to calculate integrals:

$$\hat{\dot{y}}\left(kT_e\right) = -\frac{3!}{\left(n_sT_s\right)^3}\sum_{i=0}^{n_s}\left(n_s-2k\right)T_s\ \ y\left(\left(k-i\right)\right) \tag{3}$$

This estimation technique can apply to a fast phenomenological model of process behaviour and valid in a short period:

$$\dot{y} = F + \alpha u \tag{4}$$

Where α is a non-physical constant design parameter and F represents all what is unknown on the system and can be compensated from the knowledge of the input-output behaviour of the system. In practice, the estimation of F reads from $u\left(k-1\right)$ and $\left[\hat{\dot{y}}\left(k\right)\right]_e$ as follows:

$$\left[F\right]_e = \left[\hat{\dot{y}}\left(k\right)\right]_e - \alpha u\left(k-1\right) \tag{5}$$

This estimation therefore allows the implementation of the PI-intelligent. When the closed loop controller is of PID type, the model free control can be named, intelligent PID as is expressed as follows:

$$u = -\frac{\left[F\right]_e}{\alpha} + \frac{\dot{y}_r}{\alpha} + K_P e(k) + K_I \int e(k) \tag{6}$$

Where $\dot{y}_r$ is the derivative of reference trajectory, e is the tracking error. K_P and K_I are the tuning gains. The reference trajectory is adopted according to the norms of flatness based. In our application, α, K_P and K_I were fixed at 10, 2, and 0.1 respectively.

IV. SIMULATION RESULTS

A. PID controller

The development of the model describing the evolution of the temperature under greenhouse needs to apply a step as a setpoint for heating temperature in open loop. The transfer function obtained as a first order system with pure delay could be expressed as follows (El Afou et al. (2013)):

$$F\left(s\right) = 6.1710\frac{e^{-20.6*s}}{\left(1+319*s\right)} \tag{7}$$

The parameters of PID controller are tuning from the identified system (Dindeleux (1981)):

$$K_p = \frac{\left(0.4T_r + t\right)}{120\,K\,T_r} = 2.14 \tag{8}$$

$$K_I = \frac{1}{1.33\,K\,T_r} = 0.005 \tag{9}$$

$$K_D = \frac{0.35*\tau}{K} = 18.1 \tag{10}$$

We exploit these parameters to control the model representing our system using the MATLAB software in simulation mode. To have an idea about the behaviour of the system in closed loop where the PID controller is involved, we made the model simulation in SIMULINK. Fig. 2 shows the obtained performances with the developed algorithm. We also notice that the output presents a short delay of 20 s and it perfectly follows the set point of 24 °C at 225 s.

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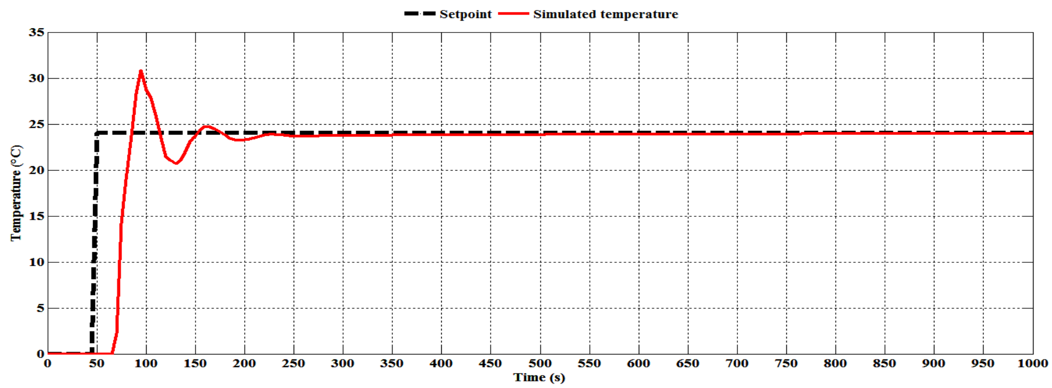

Fig. 2 Step response simulation, obtained by PID controller in closed loop.

B. PI-intelligent controller

Differentiation is a basic mathematical operation with a wide range of applications in many areas of science. It is therefore important to have good methods to compute and manipulate derivatives. In our case, the new approach named model-free control based on a derivative estimation, which we will, confirm better results even if signals are corrupted by noise. We consider the signal *y* that is available through a measurement including some additional noise. The aim is to estimate time derivatives of signal y, up to a first order, from its corrupted measurement. We can rewrite the developed numerical derivative of the first order us follows:

$$\hat{\dot{y}}(kT_e) = -\frac{3!}{(n_s T_s)^3} \sum_{i=0}^{n_s} (n_s - 2k) T_s \; y((k-i)) \tag{11}$$

In this application, we choice n_s=11 and the simple time $T_s = 5s$. Then the interval T= 55 s is sliding in order to get this estimate at each instant. We translate equation (11) to algorithm of numerical derivative implemented in Simulink as depicted in fig. 3.

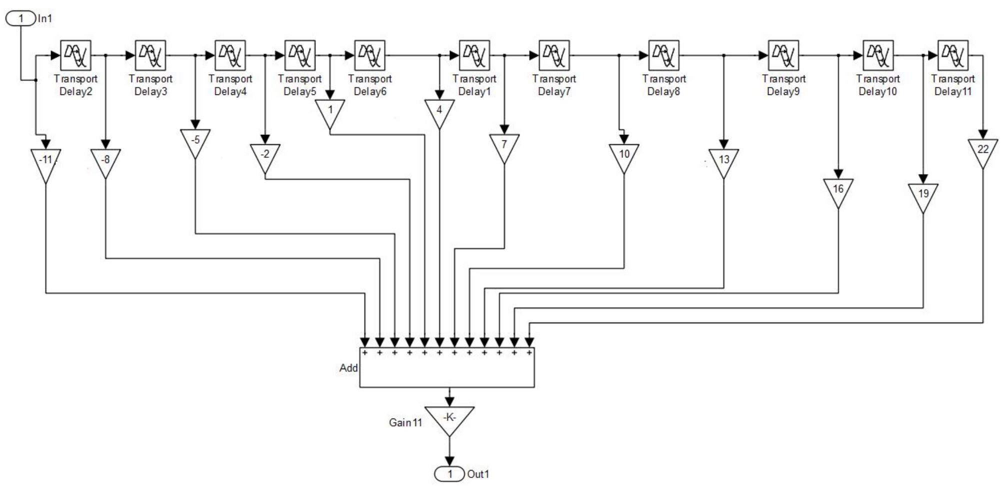

Fig. 3 Algorithm of numerical derivative.

In order to test this algorithm, we have compared the numerical first derivative with a simple derivative as depicted in fig. 4. According to this schema, we can observe the existence of some similarities between the estimated numerical derivative and the simple derivative. We conclude that the developed algorithm accurately presents a first derivative.

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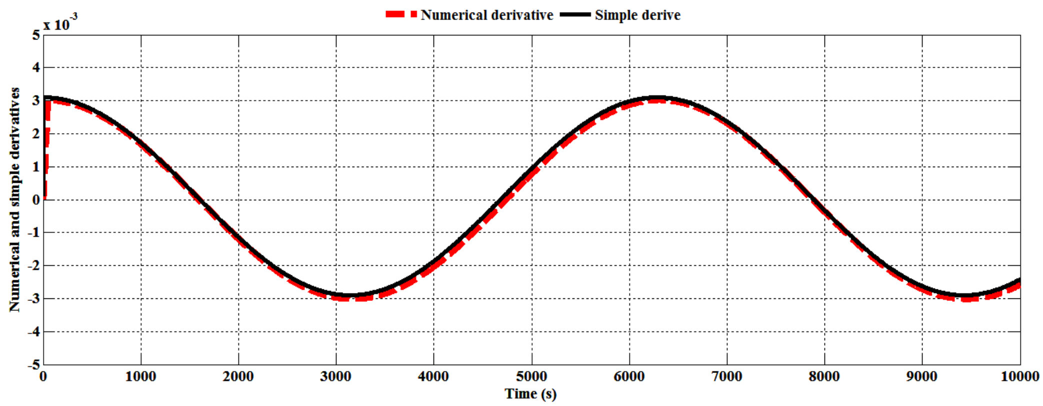

Fig. 4 Simulation of simple and numerical derivative.

To go even further, we have added a white noise to the input of derivatives. Figure 5 shows the simple first derivative and the fig. 6 presents the simulated of the first numerical derivative. It can be seen that a numerical derivation gives a good performance. The estimated first numerical derivative is better than the simple first one. The above results are the basis of the estimation techniques.

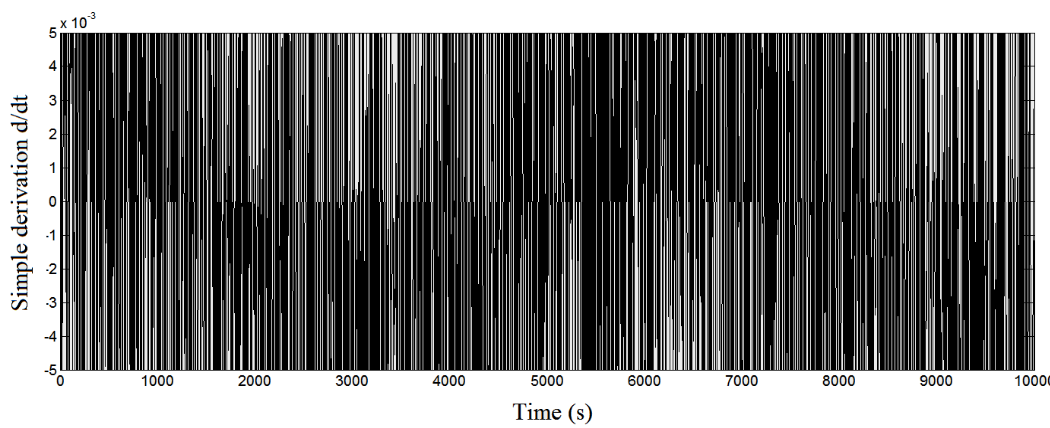

Fig. 5 Simulation of Simple derivative with added noise.

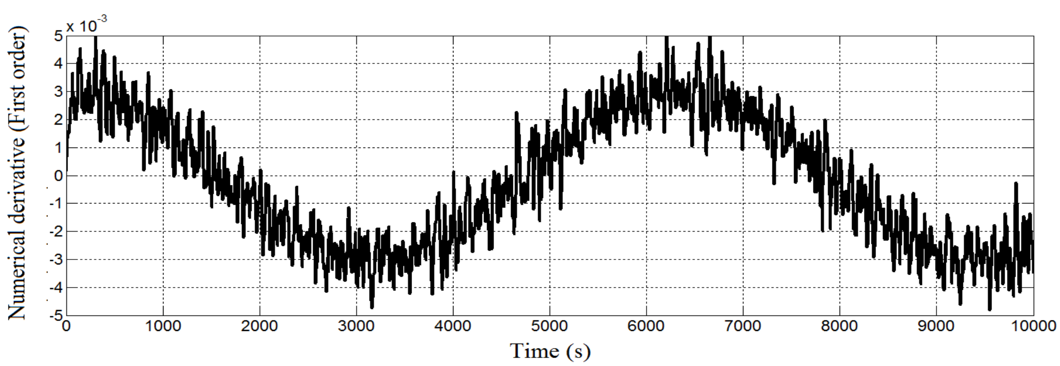

Fig. 6 Simulation of numerical derivative with added noise.

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In this paper, the study is limited just on the control of the internal temperature. Fig 7 shows the simulation results of step response of internal temperature obtained using PI-intelligent in closed loop. We note that the static error is equal to zero, the system is fast (rise time $t_m \approx 19$ s) and without overshoot. We also notice that the observed output presents at the beginning a pure delay of 20.6 s and after a duration of 350 s, it is perfectly tracking accuracy the set-point. We can improve the performances by tuning easily the parameters of this intelligent controller. Furthermore, these tuned parameters can give good results whereas the setpoint implemented with noise.

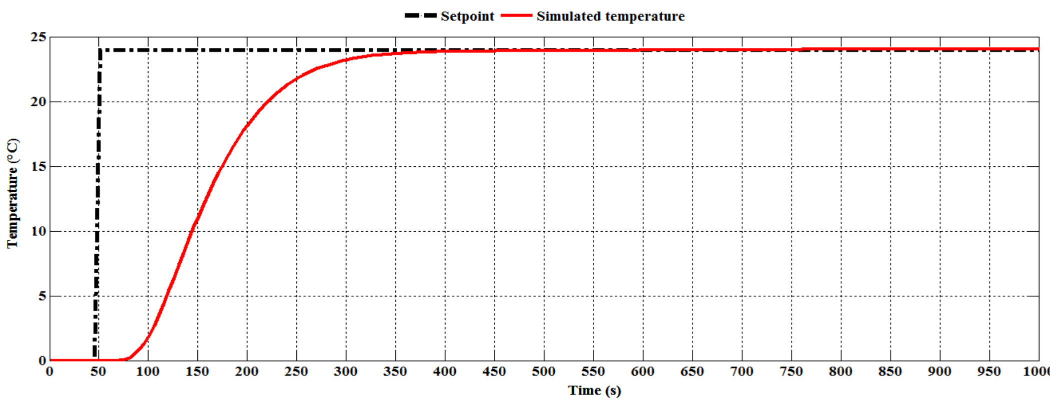

Fig. 7 Simulation of step response obtained by PI-intelligent in closed loop.

V. RESULTS OF FEEDBACK TECHNIQUES IN REAL TIME

A. Application

The inside temperature is the important parameter in the greenhouse and it influence most the culture under greenhouse (Ezzine et al. (2008)). In order to control the inside temperature, we have used two actuators heater and fan. Then we assimilate the process as a single input respectively distributed on heating and ventilation according to the value of the inside temperature and the fixed setpoint. This hybrid process makes modeling hazardous and fully justifies the model-free approach proposed. In this study, the measured relative humidity and CO_2 are not taken into account in the elaboration of control strategies. Fig. 8 shows the structure of the control system. Note that, if $[F]_e = 0$ then we obtain the classical regulator like as the simple PID controller.

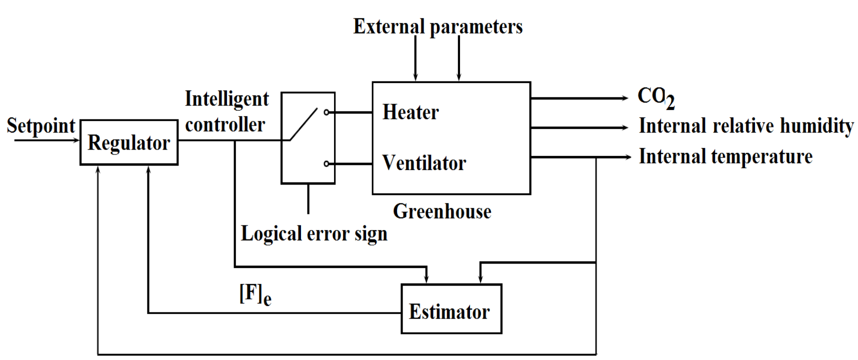

Fig. 8 Structure of the control system.

To make a controller in real time, we prepare an algorithm able to communicate with greenhouse process. For that, we began by changing respectively the Input and Output of a feedback algorithm, which is presented in the mode

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simulation, by Analog Input and Output to apply the developed algorithm on the real system. Before running a simulation, the SIMULINK must be built; some codes will be executed in the command window. If there is no error on the command window, we finally connect to a target and we run simulation by start real time.

B. PID controller

In order to test the performance of the previous controllers, we excite the actuators (heater and fan) by several set-points and we measure, in real time, the temperatures response under greenhouse. Firstly, we present the closed-loop step response of the PID controller as presented in fig. 9. We can observe that tracking is very good when the actuators are controlled by a classical law whereas it is unsatisfactory in steady state. In addition to the strong effect of the external climate, we can notice that the reference trajectory oscillates around a setpoint. Then, this controller isn't enable to reject the useless perturbations. In the fig. 9, the noises appear strongly between 7 h and 18 h.

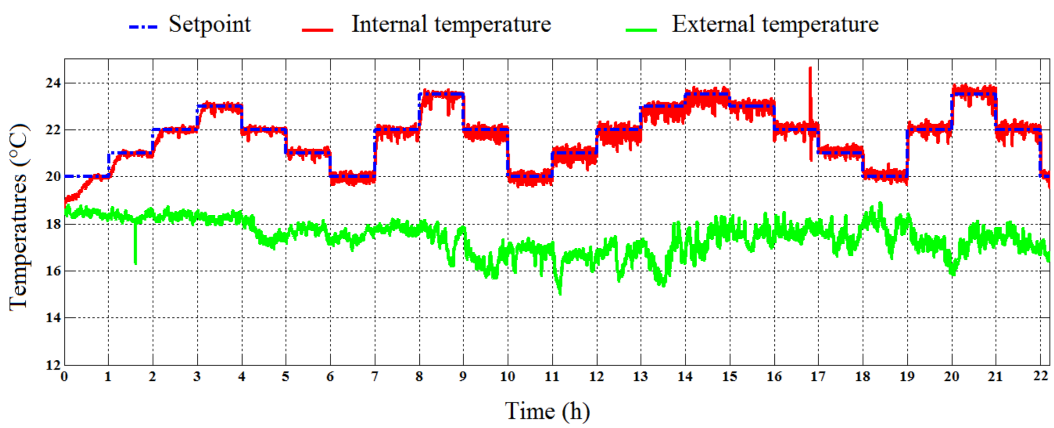

Fig. 9 Variations of external, internal and set-point temperatures.

Furthermore, we present in the Fig. 10 the evolution of the PID controller that sent to the actuators. In the beginning, this controller is growing and reach the maximum of 3 V at 15h. After that it remains stable around this value. That means the used controller cannot minimise the consumed power by the actuators. Furthermore, it presents problems overlooked lifetime of the controlled system. The poor performances are as results of the classical controllers based on the methods of identification that are not valid for large time. Moreover, these methods the later need to be actualised for each large variation of the external parameters climate. This is the reason why we are using the PI-intelligent controller for monitoring temperature under greenhouse.

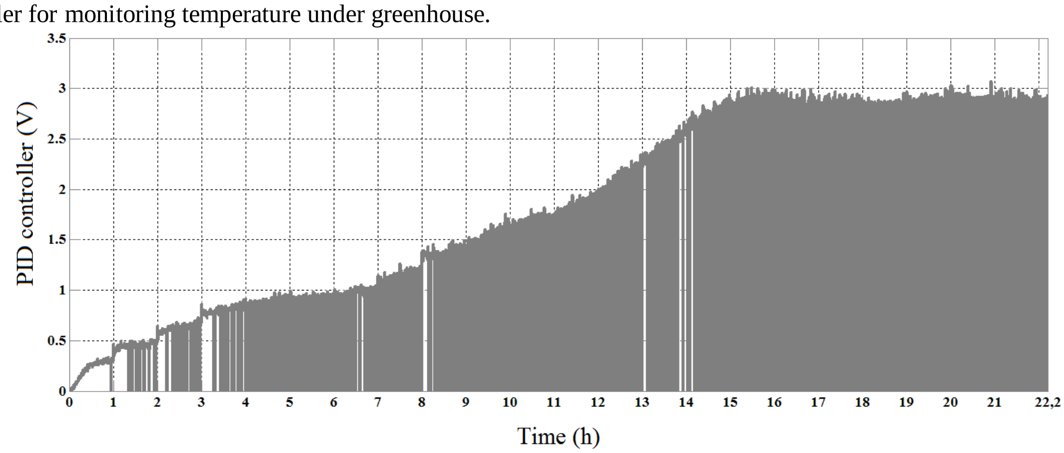

Fig. 10 Evolution of PID controller.

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C. PI-intelligent controller

Fig. 11 shows the performances of the PI-intelligent control with steps as reference trajectories that varied between 20 °C and 23.5 °C. We can observe that the perturbations are rejected faster by the PI-intelligent controller than the PID one. Furthermore, the evolution of internal temperature demonstrates that the performances of the intelligent controller behave better. The external temperature has presented to give the conditions where we are regulating the internal temperature. Although a poor conditions of the closed loop with intelligent controller, it permits to obtain the good performances. As a conclusion, the results show that the PI-intelligent controller is able to control the temperature precisely within a reasonable range of error. Its effectiveness is appearing by minimum oscillations around a setpoint and no overshoot.

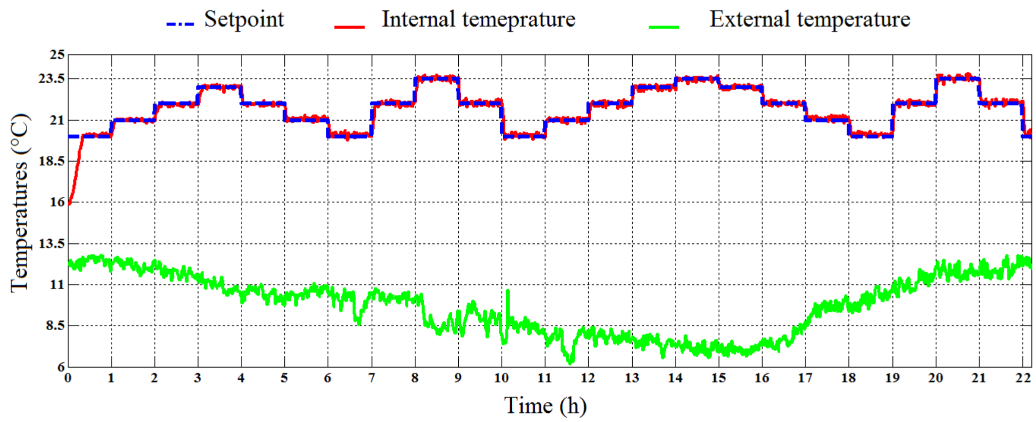

Fig. 11 Real time step response obtained by PI-intelligent in closed loop.

Similarly, we present the evolution of the PI-intelligent controller as depicted in Fig. 12. We notice that the value of the output does not exceed 1.25 V and decrease at some times. Those good performances are obtained by the fast phenomenological model of process behaviour and to the numerical derivative (equations 4 and 5). The later permits to actualize the parameter F (eq. 5) that contain all of the unknown parameters of the process. To conclude, this intelligent controller permits a good performance where we keep those parameters for large time and with a minimum power generated for real time control signals of the actuators.

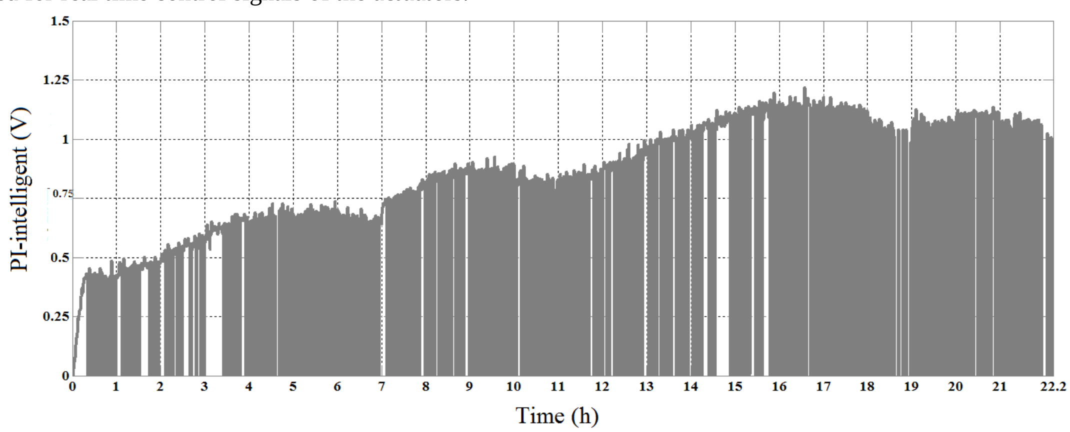

Fig. 12 Evolution of PI-intelligent controller.

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VI. COMPARATIVE STUDY

In this section, we present a comparison of the experimental results obtained by using the PID and PI-intelligent controllers. In order to facilitate the readability of curves, we chose to present regulating temperature between 2 h and 5 h. All these were performed to monitor the internal temperature of greenhouse from 21 °C to 23 °C and also to assure a fair comparison. The behaviour of temperature at the optimum PID values is shown in Fig. 13. Smooth theoretical temperature behaviour is shown with slight amount of overshoot but no ripples. Experimentally, there was more overshoot and fluctuations around the set-point. Little delay existed at the beginning of the experiment for about 20 s, which might be attributed to the air mixing delay. The PID controller made a good tracking to set-point with values of 22 °C and 23 °C. However, the maximal error of this controller is equal 0.4 °C. We can see that the number of changes in the control signals is small. This fact is a key issue in the actuator's lifetime, especially in greenhouse where the ventilation and heating systems are composed of mechanical actuators.

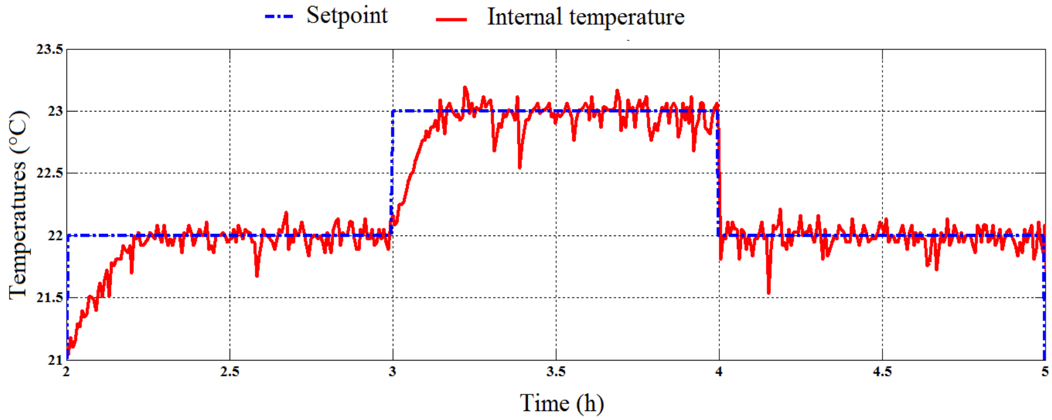

Fig. 13 Monitoring temperature under greenhouse by PID in [2, 5] h.

The optimized PI-intelligent parameter was plugged into the experimental controller as depicted in fig 14. Some fluctuations existed in the theoretical curve at the intersection with the set-point. However, a good tracking of the set-point is demonstrated with a maximal error of 0.2 °C. This controller was easy to implement and was very effective in tracking the set-point. Consequently, it made the best by means of tracking set-point.

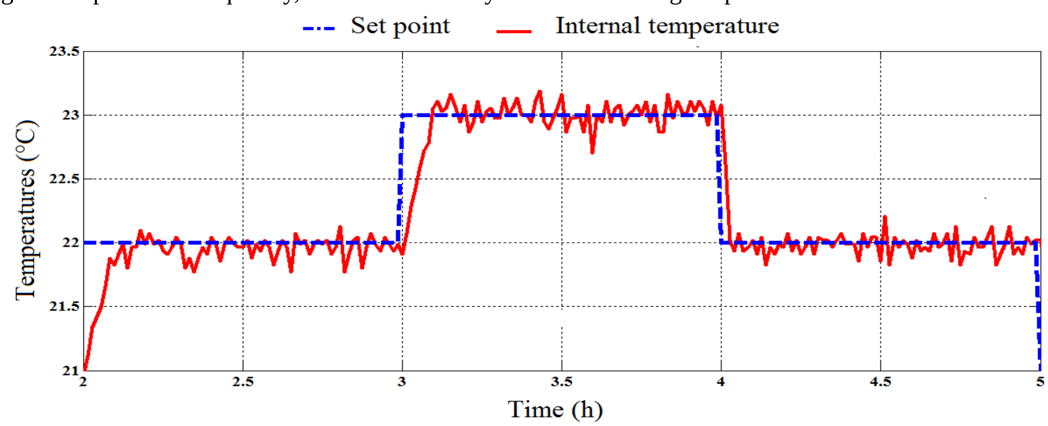

Fig. 14 Monitoring temperature under greenhouse by PI-intelligent in [2, 5] h.

All controllers were able to control the greenhouse air temperatures precisely within a reasonable range of error. We note that the values of the different initial temperatures are used because both controllers are applied under conditions within the values of different external temperatures. This makes comparative study difficult. However, we will analyse

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the results to determine the advantages and inconvenient of each used controller. Figures 15 and 16 show, respectively the evolution of commands computed by PID controller and PI- intelligent.

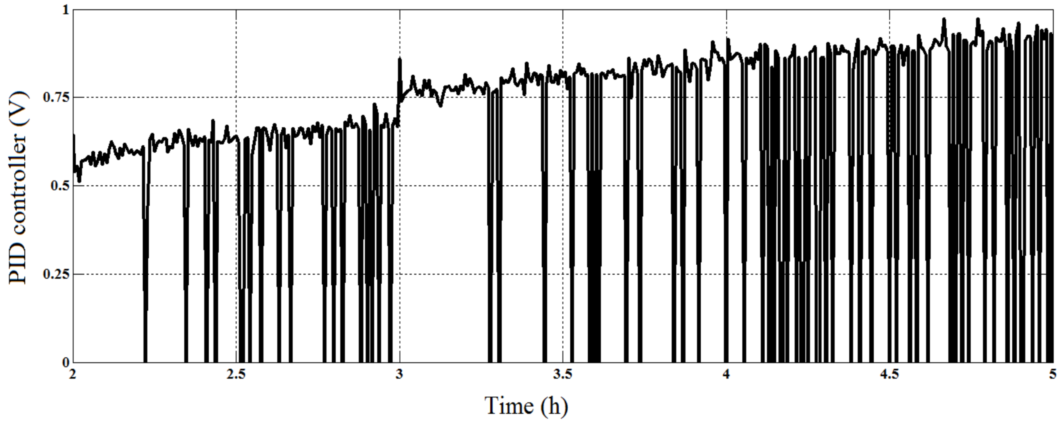

Fig. 15 Evolution of the computed PID controller in [2, 5] h.

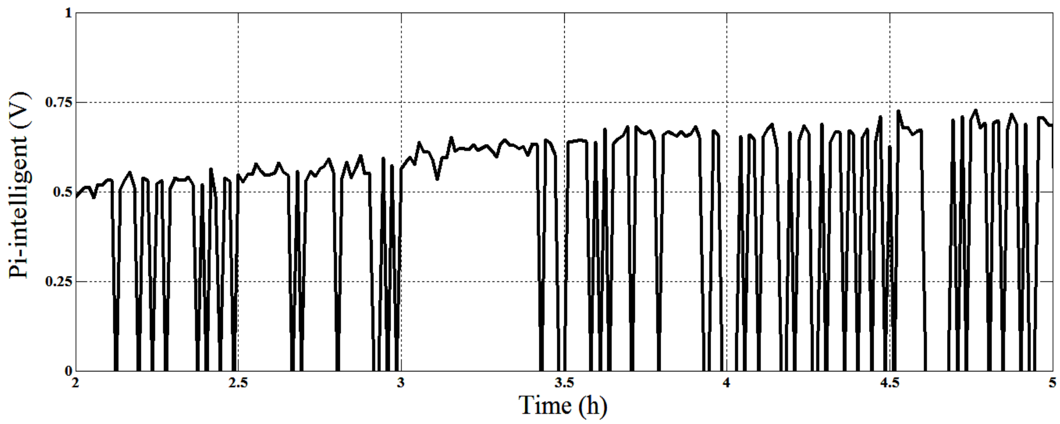

Fig. 16 Evolution of the computed PI-intelligent in [2, 5] h.

We note that the PID controller loses great power to reach the fixed objective. Indeed, it equals zero compared to other orders and the number of times the command is reset and low. However, the maximum value does not exceed 1 V. For PI-intelligent controller we note that the command is faster and stops at several moments. This evolution justifies this intelligent controller as the best method to control the temperature in the greenhouse. Despite the good performance obtained for the three orders, we note that the PID control begins to saturate because of the wide variation in climatic parameters and the limitation of the validity of the identification methods used. However, we noticed that the model free control permits to obtain a good performance, thus no saturation of used actuators.

VII. CONCLUSION

This work presents the implementation of two controllers PID and PI-intelligent which were been implemented in order to control the temperature under greenhouse. However, the tuning of several controllers in the complex greenhouse environment is a challenge to process. Usually, the tuning of most controllers was based on the techniques of identification, which are depending on the external weather conditions. For this reason, we are the recourse to the adaptive controller that can identify the process online. The fundamental difficulty with PID controller is a feedback system with constant parameters, and no direct knowledge of the process, and thus overall performance is reactive and a compromise. PID controllers, when used alone, can give poor performance when the PID loop gains must be reduced so that the output trajectory oscillates around the set-point value with no overshoot. They also have difficulties in the presence of non-linearity, do not react to changing process behavior and have lag in responding to large disturbances. To overcome these difficulties, we used the PI-intelligent controller. It was easy to implement and was very effective in tracking the setpoint. The derivative of perturbed error was estimated online for each sampling time. The PI- intelligent controller ensure good performances without having to tune again and again the PID parameters and guarantees a suitable adaptation when the plant is changing with time.

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